The Effects of Explosives in Mine Warfare. —

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THE EFFECTS OF EXPLOSIVES IN MINE WARFARE.

EXPLOSIVES. Explosives vary not so much as to the volume of gas produced, but as to the rate at which it is produced, the quicker the rate the higher the explosive. Any table however showi -ng their relative strengths is misleading as it only applies to the substance in which they are tested. For instance the ratio of Guncotton to Ammonal is stated to be 10 to14, whereas in clay it is about 10 to 25. In metal mining a fairly accurate table has been got, showing the relative values in hard rock, but even so it is years before any particular mine finds the explosive best suited for its rock. Generally speaking the harder the rock the higher the explosive used in ecomonic mining.

In destructive mining a reversal takes place, high explosives being used in soft ground generally for the purpose pf breaking enemy galleries. All tables of strengths then break down and the observer must himself find the ratio for different explosives in the different soft layers of the earth's crust. When a mine proper is required under the enemy's trenches, a lower explosive should be used but as all the observations will have been made with high explosives, it would be dangerous to use a different explosive for which no data have been obtained.

The gases from all explosives act with equal pressure in all directions, but the result of their action depends upon the resistances met with and their direction depends on a combination of the resultant of the areas of resistance and is not necessarily at right angles to either.

within a plastic homogeneous substance the gas would continue to form a spherical cavity until the external pressure equalised the pressure of the gas. Different charges of the same explosive form volumes of gas proportional to their weights. In a homogeneous substance therefore the size of the cavities formed by the gas would be proportional to the weight of the explosive; in other words the charge varies directly as the volume of a sphere, and as the volume of a sphere varies as the cube of its diameter - the charge Diameter^3
Radius^3
The desired radius^3

All explosions produce at least five radii : disentegration, shearing, total rupture, fracture, and shock. In mine warfare only two of these radii affect the object to be attained :- the radius of rupture applies to the wrecking of enemy galleries.

The radius of shear applies to mines forming craters. For the same explosive in the same ground the radius of shear will always bear a definite and constant ratio to the radius of rupture at any depth (for Ammonal in chalk it is about two-thirds) so it only remains to find the radius of rupture.

RADIUS OF RUPTURE.

In the ground, a homogeneous substance horizontally, the charge varies horizontally as the cube of the Radius of Rupture. The Radius of Rupture is generally taken to mean the radius at which a well timbered unprotected gallery 4' x 2½' would be completely crushed, but this radius varies within certain limits depending on local conditions known only to the observer, such as tamping, compactness of charge, size, strength and direction of gallery tamped, previous blows, the dead weight of loose ground above gallery, the distance to surface and proximity to enemy gallery being of less importance than any one of these points. As a rule there is a very sharp line between total and partial rupture, the latter in clay sometimes extending 25 feet beyond total rupture, but much less in chalk. The R.R. besides varying according to the ground, varies in similar ground according to its water contents, a water logged chalk, clay or sand having a greater R.R. than when dry, the R.R. increasing with the incompressibility of the soil, water being incompressible and filling the pores of dry material which otherwise would tend to absorb the shock by its air spaces in joints and pores. Galleries therefore should be kept above the water level at all costs.

To find the R.R. it is necessary to have a trial explosion, preferably a camouflet with greatest charge possible, but two are better, a high and a low charge, in both of which the observed and calculated R.R. can be compared and the mean of each taken, the R.R. of other charges calculated from the higher, calculation from the lower leading to large errors for high charges. Having exploded one mine and noted the R.R. any further R.R. or charges can be easily calculated from the following formulae :-

Let a equal the required R.R. in feet
x " the required charge in pounds
b " the noted R.R. in feet
y " the corresponding charge

We have seen that the charge varies as the cube of the desired radius, then x : y equals $a^3 : b^3$

1. Formula for R.R.

$$a = \sqrt[3]{\frac{x}{y} \times b^3}$$

2. Formula for charge

$$x = \frac{a^3}{b^3} \times y$$

There is only one unknown; for either the R.R. of a known known charge is required or vice versa. It cannot be too strongly pointed out that the perpendicular between charge and surface (miscalled the line of least resistance) in unbroken ground, has no bearing whatever on the R.R.

The above formulae were not obtained from theory, on the contrary formula No. 1 was evolved from practical results and worked backwards to find the theory which agrees absolutely with what one would expect, and has stood two months test for charges between 500 and 6000 lbs: further the attached table was worked out for soft broken chalk of 10 to 15 feet deep, but on comparison with explosions in hard chalk 50 feet deep, there was surprisingly little difference noted. The table is then offered not as the last word, but as a rough guide for horizontal R.R. upon which to base initial charges in chalk at any depth above water level, until such time as the observer has himself got out a table applicable to his own ground and plotted it on squared paper.

It has been noted that the horizontal R.R.

agrees absolutely with theory, but vertically it is not so. The resistance is naturally greater for ground vertically below, because it is less capable of expansion, and for camouflets 15% should be deducted for galleries below but it is far better for Officers to use their own judgement and note the result, than to attempt any calculations from compiled formulae, which have at the best been obtained from charges which are minute compared with those employed in underground warfare.

THE RADIUS of SHEAR (R.S.)

An explosion that breaks surface from below is called a mine and the surface cannot be broken until it is forcibly removed along the line of shearing plane which is called the radius of shear. The formulae are found in a ~~xxx~~ similar way to those for R.R., for the radius of shear applies equally to a whole sphere of that radius, not as might at first sight appear only to the disrupted sector of the sphere.

The initial R.S. can only be found by trial as the initial R.R. must be found, and a camouflet that just breaks surface gives the R.S. This for Ammonal in chalk was noted to be approximately two-thirds of the R.R. and so a table can at once be got by dividing all the observed and calculated R.R. by two-thirds, e.g.

3000 Ammonal = 63 R.R. = 42 R.S.

FORMULAE for CRATERS.

It is first necessary to get the R.S. corresponding to the required crater diameter. As craters are always measured from lip to lip, it will be necessary for purposes of calculation to deduct 20% from this false diameter to obtain the true one at solid crater surface level.

The shearing radius required for the crater is the line joining the true edge of the crater with the middle of the charge.

The perpendicular from charge to surface is known as R.S.

P = Perpendicular from charge to surface in feet.
C = True radius of crater required in feet.
S = Shearing radius required for crater.

$$S = \sqrt[2]{P^2 \text{ plus } C^2} \quad \text{(Euclid I. 47)}$$

and can preferably be found graphically.

Formula for charge :-

S = R.S. to crater edge found as above in ft.
X = Charge required for crater in pounds.
P = Known R.S. to surface.
Y = Corresponding charge for R.S. to surface.

Then $$X = \frac{S^3}{P^3} \times Y$$

$$S = \sqrt[3]{\frac{X}{Y} P^3}$$

It is easy to get a formula but to get accurate results from inaccurate data is not possible. The true crater diameter can only be roughly estimated, the true depth of the charge is rarely known within a few feet, every foot making a large difference in the calculations. The charge too may not be correct. With all these drawbacks however a good approximation can be arrived at.

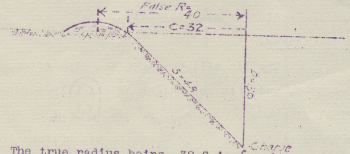
EXAMPLE of CRATER in CHALK.

It was noted that a charge of 3000 lbs Ammonal nearly broke surface at a depth of about 42 feet (the centre of charge therefore was 40 feet, and at 42 feet the ground would have been broken) what charge will be required to produce a crater of 80 feet diameter at a depth of 36 feet.

First find the charge at 36 feet corresponding to that at 42 feet from table or

$$\text{Charge} = \frac{36^3}{42^3} \times 3000$$

To find value of S. graphically = 48



The true radius being 32.S is found graphically to be 48 as above.

$$\text{Then charge} = \frac{48^3}{36^3} \times \frac{36^3}{42^3} \times 3000$$

Note: A charge of 5000 lbs Blastine at about 35 feet made a crater of 78 feet.

EXAMPLES in WATER-LOGGED BLUE CLAY.

At about 20 feet deep it was noted that 80 lbs Ammonal did not touch surface but that 120 lbs formed a good crater, therefore 100 lbs is taken as R.S. at 20 feet. 550 lbs Ammonal at about 20' deep made a crater of about 70'. The charge calculated as above comes to 500 lbs

About 900 lbs (30 bags) Ammonal at about 20 feet deep made a crater about 100 feet. The calculated charge comes to 1150 lbs.

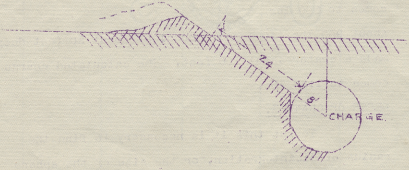
DEPTH OF CRATERS.

To get this it is necessary to find the radius of disintegration, or the size of the sphere within which the ground is totally disintegrated into the finest powder, or to use a popular expression, the depth to which the charge will "strike down". This by experiment was found to be about one-quarter of the R.S.. The depth of the crater, then, will be the sum of the height of lip, the depth of the charge below surface and the radius of disentegration.

CROSS-SECTION OF CRATERS.

The lip will be along the line of shear produced, and upon the height of this lip depends the final diameter of the crater. The height of this lip depends on the amount of Earth thrown up, but when the true crater radius is greater than the depth below surface, then a flat lip will be made, when less a steep lip in unblown ground.

The true section will therefore be from the lowest point of the radius of disentegration and along irs circumference to its vertical tangent. Along this tangent to its point of intersection with the R.S. and along the R.S. produced to the estimated lip.



CONCLUSION. A table for Ammonal in Chalk is appended, as an example, and by plotting these on squared paper, the charges for mines and Camouflets can be read at a glance, the dotted lines showing the variation which the observer may make for himself.

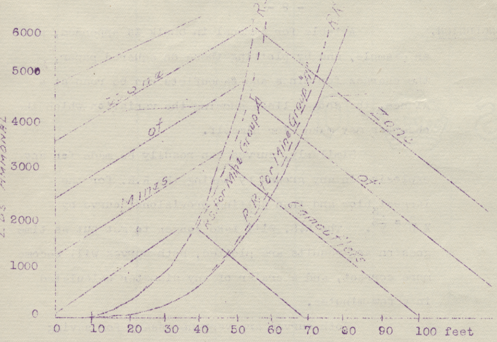
Similarly, curves can readily be made for any explosive in any ground by taking the R.R. for the largest blow and then getting provisional curve by $X \frac{a}{b} = \frac{x^3}{y^3}$. The R.S. will take longer to get but as time goes on and results are plotted, both curves will become more correct, and a crater of any diameter calculated in a few minutes.

Both curves are very necessary for saving unnecessary amounts of explosives being used, and one's galleries from fracture. Tamping is so highly important that a few notes are added on this subject.

TABLE OF CHARGES FOR CHALK (Provisional)

R.R. = Radius of Rupture in chalk for Ammanal
R.S. = Radius of Shear in Chalk for Ammonal
R.S. = (2/rds R.R.)

Lbs. Ammonal	R.R.	R.S.
100	20 ft	13 ft
250	28	18
500	35	23
1000	44	29
1500	50	34
2000	55	37
3000	63	42
4000	70	47
5000	75	50
6000	79	53



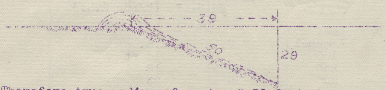
Examples from squared paper curves.

(1) Charge at 4500 has R.R. of 72 feet.

(2) At 48 feet charge of 4250 just breaks surface (R.S.)

(3) At 29 feet a charge of 100 just breaks surface (R.S.)

At 29 feet a charge of 5000 has an R.S. of 50 feet.



Therefore true radius of crater = 39 feet.

Therefore true diameter of crater = 78 feet.

Therefore false diameter of crater = 98 feet approximately.

TAMPING This is by far the most important factor affecting the R.R. in unblown ground. The tamping material is the most vital point, loose lumps of chalk in sandbags being the worst possible, the real line of least resistance being in all cases the tamped gallery. Intermediate loose tamping is not so important provided that the first five feet is hermetically sealed with loose wet material, also the last five feet.

The size of the gallery and the placing of the charge also affect the shock.

The gallery must be tamped solid for the full calculated R.R. the area of greatest weakness in unblown ground playing very little part in the rupture. Air spaces are fatal but beyond the R.R., a few barricades, one sand-bag thick placed three apart, help to cushion the rush of air and save the gallery from fracture, and the solid tamping from being pushed out and displacing the timber. There is no fear of gas as the top sand bags will be blown off. Five to ten feet of gallery within the R.R. can be generally recovered by this precaution.

To save galleries adjacent to the blow, which are most affected when at right angles to it, it is best to fill every set with sandbags, also to cover the floor to modify the upward kick. If time does not permit stretchers should be put across horizontally the middle of the sets, care being taken to leave by means of wedges half an inch of space on either side between the cross stretchers and the legs.

PROVISIONAL TABLE.

OF

Radii of Shear (R.S.) and Rupture (.R.R.) in Chalk.

AMMONAL.

Pounds	R.R.	R.S.
50	20	
100	20	13
150		
200		
250	28	18
300		
400		
500	35	23
600		
700		
800		
900		
1000	44	29
1500	50½	34
2000	55	37
2500		
3000	63	42
4000	70	47
5000	75	50
6000	79	53
7000	83½	56
8000	87	58
9000	91	61
10000	94	63
15000	108	72
20000	118½	79
25000	128	85
30000	136	91
40000	149½	100
50000	161	107
60000	171	114
70000	180	120
80000	188	126
90000	196	131
100000	203	135

PROVISIONAL TABLE.

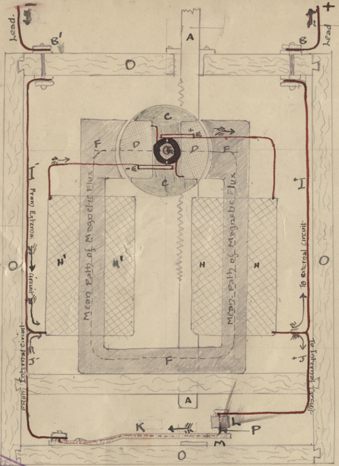
for

Horizontal Radius of Rupture in Clay.

	Guncotton		Ammonal	
Pounds	R.R.	R.S.	R.R.	R.S.
10	11 ft		16	
20	14		21	
3P	16		24	
40	18		26	
50	19		28	
60	20½		30	
80	22		33	
100	24		36 ✓	22
120	25½		38	
150	28		41	
200	30½	22	45	
300	35		51½	
400	38½		57	
500	41½		61	
600	44		65	
700	46½		68	
800	48½		71½	
900	50½		74	
1000	52		77	
1500	59½		88	
2000	66		97	
2500	70½		104½	
3000	75½		111	
4000	83			
5000	89½			
6000	95			
7000	100			
8000	104			
9000	109			
10000	112			

Note: For Guncotton the R.S. is a little more than 2/3 R.R. in this table.

For Ammonal the R.S. is a little less than 2/3 of R.R. in table.



AUSTRALIAN WAR RECORDS SECTION
D 335 · 1 /
CLASSIFICATION SUB-SECTION

Sectional Sketch of Electrical Exploder
showing
Diagram of Electrical Circuits.

Essential Parts.

Indicat-ion	Description
A	Driving Rod with rack
B	Positive Terminal
B'	Negative Terminal
C	Armature (shuttle wound)
D	Armature Winding
+E	Positive Brush (copper)
-E	Negative " "
F	Field Magnet (soft iron)
G	Split-ring Commutator
H	Field Windings
+J	Copper Strip connecting H to B'
-I	" " " H to B
+J	" wire " H to K
+J	" " " H to L
K	Flat Steel Spring
L	Brass Bridge over K
M	Rubber Cushion
O	Wood Casing
P	Contact Point (screw)

Explanation. Of Mode of Action

THE INTERNAL CIRCUIT

The driving-rod "A" rotates the armature "C" by means of a rack and pinion gear. On the upward stroke, the armature remains stationary, the pinion running free on the armature shaft by means of a "ratchet".

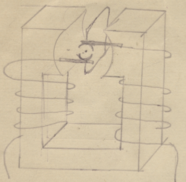
When the driving-rod "A" is pushed down, the armature rotates between the poles of the Field-magnet "F". The current thus induced in the armature, is taken off at the split-ring commutator "G", by +ve copper brush E, and is then conducted through the field winding "H" which is "in series" with the armature winding D.

The current is then conducted to the brass bridge "L" by copper lead +J. The spring "K", pressing up against the contact screw "P", conveys the current to the other field winding H' through lead -J. The current, after passing through the field-winding H' is led back to the armature winding through negative brush -E, and split-ring commutator G Thus completing the INTERNAL CIRCUIT

THE EXTERNAL CIRCUIT

When the driving-rod reaches the "bottom" of it's stroke, it presses the steel spring "K" on to the rubber cushion "M" thus opening (or breaking) the internal circuit. When the internal circuit is broken, the MAGNETIC flux (or FIELD), which passes through the soft iron core of the field windings H and H', is reduced from one of great intensity to one of rare intensity. This sudden change of "flux" induces a current in the EXTERNAL CIRCUIT and explodes the detonator.

Electromagnetic Principles on which Exploder is Constructed



ROYAL ARTILLERY
No. RA/83
Date 15/9/16
ANZAC MOUNTED DIVN.

CRA for information & return D D A G

GENERAL STAFF
No.
Date
ANZAC MOUNTED DIVN.

15

DSO Noted & returned

Attached table sent to CRA 10/9/16

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Ia/7360.

THE EFFECTS OF EXPLOSIVES.

BEING

Chapter II. of the "ÉCOLE DE MINES (Livre de l'officier)."

(*Translated from the French.*)

AUSTRALIAN WAR RECORDS SECTION
D 3351/1
CLASSIFICATION SUB-SECTION

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1. GENERAL.

61. The effects of explosives in a homogeneous and unlimited medium.

Solid medium.—The simplest theoretical example is that of an explosion in an approximately homogeneous solid medium, which surrounds the charge in a layer so thick that it may be considered as unlimited and whose elastic limit is not exceeded when it comes under the pressure of the gases. The elastic medium yields in a progressive manner, its resistance increasing directly with the increase in size of the cavity V (fig. 1, at end), which is formed by the expansion of the gases. This cavity is called the *compression chamber*. Immediately the decomposition of the charge is completed the gas pressure decreases, owing to the temperature becoming lower—the solid molecules that have been displaced have then a tendency, owing to the elasticity of the medium, to take up their original positions. In their turn they exert pressure on the products of the decomposition of the explosive. For equal charges, the smaller the size of the compression chamber the greater is the force exerted upon the medium, that is to say, the greater is the resistance of the medium.

In practice, when high explosives are employed, the elastic limit is always exceeded; the medium in the immediate neighbourhood of the charge is crushed, and provided it is sufficiently plastic, the compression chamber is not filled up again after the gas pressure has dropped.

The existence of the compression chamber can be easily observed when a mine is fired in clay. In a medium which is very tough but lacks plasticity, for instance, a mass of masonry and rock, a hollow space that does not fill up again is still formed around the charge, especially if a high explosive is used. This result is chiefly due to the matter in the immediate vicinity of the explosive being crushed and pulverised.

The pressure arising from the explosion gases is gradually transmitted from the charge, through the solid medium, but with ever diminishing intensity. Thus one can imagine about point O (fig. 1) a series of hollow spheres which correspond to points of equal maximum pressure, and the dimensions of which become greater as the pressures decrease. One can even conceive the surface of one of these spheres which is called the *deformation limit surface*, at which the pressure due to the gases is equal to the limiting resistance of the medium. Inside this surface the effects of the explosion are generally exhibited by the crushing of whatever matter may be present there, the breaking up of the ground, and fissures of varying depths. Beyond this surface no further permanent deformations are to be observed, although the shock produced by the explosion may have been felt much further.

Liquid medium.—A liquid medium which has practically no cohesion can only offer resistance through its weight and its inertia. In the interior of the mass of the liquid are produced firstly, displacements which spread to the exterior; and secondly, very powerful compression effects which are transmitted to a very great distance.

The compression chamber only has a temporary existence, because the explosion gases are dissolved, or are ejected into the air by the pressure of the liquid.

Gaseous medium.—Resistance to compression is exceedingly slight, cohesion does not exist, and the weight is negligible. The gaseous medium therefore offers resistance

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only on account of its inertia, the effect of which is in direct ratio to its density and its displacement, and in inverse ratio to the square of the time during which the displacement takes place. The pressure of the explosion gases on such a medium is therefore greater the shorter the time the explosion lasts, and it is for this reason that it is even considerable in the case of high explosives whose detonating effects travel at a velocity of several miles per second.

This explains the destructive effects obtained with high explosive charges upon very hard bodies in the open air, whereas in the same circumstances black powder can only produce comparatively feeble compression effects. To increase these, the gas in contact with the explosive must be replaced by a medium of greater density, either liquid or solid, which will form a partial tamping.

62. **The case of several media.** (Line of least resistance.)—Two media, M and M′ are separated by a continuous surface, XY (fig. 2); medium M is solid and resistant, and medium M′ is liquid or gaseous. If the charge is in medium M at such a depth that the "deformation limit surface" (*see* Section 61) is entirely within this medium, surface XY and medium M′ will remain intact. If, however, the charge be gradually brought closer to XY, the "deformation limit surface" of medium M will form a tangent with surface XY, and by continuation of the movement will intersect surface XY, which will then be disturbed. This deformation will take place around point A, the closest to O, where the stresses are greatest. The line OA is called the *line of least resistance* (L.L.R.).

63. **Craters.**—If the charge O be brought closer still to XY (fig. 3), medium M will spread more and more into medium M′, fragments of it being violently thrown into the latter. Thus the compression chamber made in medium M will break out on the side next to medium M′ along the L.L.R. OA, and will form an excavation called the *real crater*. Immediately afterwards fragments ejected by the explosion will fall back, and may partly refill the real crater. The excavation then remaining is called the *apparent crater*, or simply the *crater*.

When a crater is formed, part of the expansion of the gases produced may take place in the space presented by the breaking of the compression chamber before it reaches the maximum pressure that it could have attained in an unlimited medium M. The deformation limit surface in this medium will become smaller and smaller; which amounts to saying that the interior effects will decrease. This decrease will be specially marked in the case of slow burning powders; in the case of high explosives on the contrary, the distance OA may be made very short without very greatly decreasing the destructive effect of the explosion on medium M.

64. **Surface charge.**—The charge is said to be a *surface charge* when its centre is in the neighbourhood of surface XY (fig. 3). The expansion of the gases in medium M′ is only hindered by the inertia and the weight of the liquid or gaseous molecules of this medium. If it be a liquid, its resistance will always be sufficient for the destructive effects of the explosion on the solid medium M to have a useful practical result even with a slow burning powder. If it be a gas (*e.g.*, a charge exploded in the open air), a charge so placed will only have a useful practical effect on M if a high explosive is used.

If the charge is placed entirely in the less resisting medium M′, its action on M decreases rapidly as the distance separating it from XY increases, even if the most powerful explosives are employed. This phenomenon is found to occur more particularly in connection with demolition work in the open air, when the charge is not in perfect contact with the structure to be destroyed.

65. **The case of several lines of least resistance.**—If the medium M in which a charge is fired is bounded by two surfaces, XY and X′Y′, towards two less resisting media, M′ and M″, two L.L.R., OA and OA′, must be taken into account (fig. 4). When the length of one of these two lines, OA′, is sufficiently great to prevent the pressure due to the gases from overcoming the resistance of medium M at any point on X′Y′, the results are as in the case of only one L.L.R., OA. In the case of the gas pressure being sufficiently great to break the equilibrium of both surfaces, XY and X′Y′, in the neighbourhood of A and of A′, deformations, or even ejection of matter, &c., will occur on both sides. The commotion is greater on the side of the shorter L.L.R., OA, than on the side of the longer line, OA′; the commotion is, however, less than it would be were there only one L.L.R. resistance.

2. EFFECTS OF MINES AND CALCULATION OF CHARGES.

Mines Charged with Powder and Entirely Underground.

66. **Definitions and general data.**—If O (fig. 5) be the centre of a charge of powder, whose weight is C and whose shape is either spherical or cube, is placed at a depth $OA = h$, below the surface of the ground XY, which is supposed to be horizontal, then h will be the L.L.R. of the mine (*see* Section 62). When h is so short that the deformation limit intersects the surface of the ground XY, exterior effects will be obtained.

The ground is thrown up by the explosion and forms an inverted cone with a crater CGB, which is more or less filled in by the falling back of the soil. The edge of the crater at the surface of the ground is a circle of which the radius r is called the *radius of the crater*.

In compact soil, if the ejected ground be carefully removed, the *real crater* CEMKNDB will be discovered. If the soil is friable, the section of the real crater CMKNB will only vary slightly from a paraba.

The line OB connecting the centre of the charge and the edge of the crater is called the *radius of rupture*.

At the surface the ground is forced up, disturbed, and cracked beyond the edge of the crater for a distance AI, which is called the *radius of the friability circle*. The distance OI from the centre of the charge to the friability circle is called the *radius of friability*. The friability circle may be considered to represent, with sufficiently exact approximation, the line on the ground corresponding to the "deformation limit surface."

67. **Classification of mines.**—In any specified kind of soil, and for a given depth h, if $r = h$ with a charge of powder C, r will be greater than h for a charge greater than C, and r will be smaller than h for a charge smaller than C.

The proportion $n = r/h$, which gives the size of the crater, is called the *index of the mine*.

The following nomenclature is adopted:

Common mines, $r = h$ or $n = 1$,

Overcharged mines, where $r > h$ or $n > 1$,

Undercharged mines, where $r < h$ or $n < 1$.

In this last category are included mines that do not form a crater, and which are called *camouflets*.

68. **Common mines.**—It has been found by experiment that, in the same kind of soil, charges which form common mines are in proportion to the cube of the L.L.R. H; one therefore has

$$C = gH^3 \quad \text{or} \quad H = \sqrt[3]{C/g},$$

where g is a coefficient depending upon the cohesion and the density of the soil.

The charges being in kilogrammes and the L.L.R. in metres, the following values of g have been obtained:

Light soil	1·20
Heavy sand (stiff sand)	1·75
Earth mixed with stones	2·00
Clay mixed with chalk	2·25
Medium masonry	2·50
Rock, good ordinary masonry	3·00 to 4·50
Hard and compact rock, concrete	4·50 to 7·00

It is, however, as well to consider these values as only a first approximation, and to rely upon experiments specially made on the ground which has to be dealt with.

TABLE showing the charges which will produce common mines when placed at different depths in media whose coefficient g is between 1·20 and 7.

$$C = gH^3, \qquad H = \sqrt[3]{C/g}.$$

H/g.	1·20.	1·75.	2·00.	2·25.	2·50.	3·00.	4·50.	7·00.
m.	kg.	kg.	kg.	kg.	kg.	kg.	kg.	kg.
1·00	1·20	1·75	2·00	2·25	2·50	3·00	4·50	7·00
1·25	2·34	3·41	3·90	4·39	4·88	5·85	8·78	13·7
1·50	4·05	5·91	6·75	7·59	8·44	10·1	15·2	23·6
1·75	6·43	9·38	10·7	12·1	13·4	16·1	24·1	37·5
2·00	9·60	14·0	16·0	18·0	20·0	24·0	36·0	56·0
2·25	13·7	19·9	22·8	25·6	28·5	34·2	51·3	79·7
2·50	18·8	27·3	31·3	35·2	39·1	46·9	70·3	109
2·75	25·0	36·4	41·6	46·8	52·0	62·4	93·6	146
3·00	32·4	47·3	54·0	60·8	67·5	81·0	122	189
3·25	42·2	60·1	68·7	77·2	85·8	103	154	240
3·50	51·5	75·0	85·8	96·5	107	129	193	300
3·75	63·3	92·3	105	119	132	158	237	369
4·00	76·8	112	128	144	160	192	288	448
4·25	92·1	134	154	173	192	230	345	537
4·50	109	159	182	205	228	273	410	638
4·75	129	188	214	240	268	322	482	750
5·00	150	219	250	281	313	375	563	875
5·25	174	253	289	326	362	434	651	1010
5·50	200	291	333	374	416	499	749	1160
5·75	228	333	380	428	475	570	855	1330
6·00	259	378	432	486	540	648	972	1510
6·50	330	481	549	618	687	824	1240	1920
7·00	412	600	686	774	863	1030	1550	2400
7·50	506	738	844	949	1050	1270	1900	2950
8·00	614	896	1020	1150	1280	1540	2300	3580
8·50	737	1075	1230	1380	1540	1840	2750	4300
9·00	875	1280	1460	1640	1820	2190	3280	5100
10·00	1200	1750	2000	2250	2500	300	4500	7000

69. **Common mines. Exterior effects and effects due to the friability of the ground.**—By the definitions given we have

Radius of the crater $\qquad r = H,$

Radius of the explosion $\quad R = \sqrt{H^2+r^2} = H\sqrt{2}.$

Experience further shows that we have

Depth of the crater $\quad p = H/3,$

Radius of friability $\quad F = 1{\cdot}4 \,.\, R = 1{\cdot}4 \,.\, H\sqrt{2}.$

Therefore

$$\sqrt{2} = 1{\cdot}4.$$

From which we find

$$F = 2H.$$

Looking at triangle AOI (fig. 5) we have

Radius of friability circle $\quad f = \sqrt{F^2-H^2} = H\sqrt{3}.$

70. **Common mines. Interior (underground) effects.**—The radius OM of the compression chamber (fig. 5) depends upon the nature of the soil. Experience shows that, for the same kind of ground, it is in proportion to the cube root of the charge; in other words, volume V of the compression chamber is proportionate to the charge C. Thus one has V = KC, the coefficient K being constant for the same kind of ground.

In any system of mines, the underground effects are also defined as the distances at which charges placed in the ground act upon galleries, branch galleries and shafts. The greatest of these distances is the same as the deformation limit surface (*see* Section 61), which probably is approximately a sphere of which the radius is practically the same as the radius of friability. Moreover, the pressures transmitted through the ground in any direction vary nearly in the inverse ratio to the square of the distance to the centre of the charge.

71. **Good rupture and limiting rupture.***—In practice there must be taken into account 1st, the minimum distance, called that of "limiting rupture," at which a gallery must be from the centre of the powder, in order not to be damaged by the explosion of the charge; 2nd, the maximum distance, called that of "*good rupture*," at which a gallery may be sufficiently seriously damaged to be put out of use. It is considered that this result has been attained if the gallery is broken down for a distance equal to 2H.

As the topsills of the gallery frames have a greater cross-section and are shorter than the stanchions, the *limiting rupture limit* is smaller in a vertical direction than it is in a horizontal direction. In order to ascertain the radius of rupture for an intermediate position: on a vertical plane passing through the centre of the charge, O (fig. 6), describe an ellipse having the same point O as centre, whose semi-axes are the vertical radius and the horizontal radius of limiting rupture. It is considered that a gallery is beyond the reach of the effects of the explosion if it be outside the ellipsoid of revolution produced by revolving the above ellipse round its vertical axis. In the case of a mine which forms a crater, this rule can only be applied to galleries which are below a horizontal plane passing through the centre of the charge; for any position above this plane, the radius of limiting rupture is greater than the vector radius of the ellipsoid in question.

Similarly there is a *horizontal radius of good rupture* and a *vertical radius of good rupture*, which serve to describe an ellipsoid of good rupture analogous to that of limiting rupture. It is considered that a gallery, level with, or below, the centre of the charge, must at least be tangential to this ellipsoid in order to ensure that it will be broken into for a sufficient length.

In the case of the common gallery we have

Horizontal limiting rupture radius : $7/4H,$

Vertical limiting rupture radius : $H\sqrt{2},$

Horizontal good rupture radius : $H\sqrt{2},$

Vertical good rupture radius : H.

The resistance offered by galleries varies according to their size and the manner in which they are made, to whether they receive the force of the explosion end on or on one of their sides, and to whether they are empty or tamped. Fig. 7 shows the values of radii of horizontal limiting rupture for the different types of galleries and branch galleries, empty or tamped, taken in flank or end on.†

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* "Ellipsoide de bonne rupture," the ellipsoid whose semi-axes are the vertical and horizontal radii of good rupture respectively. "Ellipsoide de rupture limite," the ellipsoid whose semi-axes are the vertical and horizontal radii of limiting rupture respectively.

† Galerie majeur has been translated great gallery,
Grande galerie „ „ common „
Demi „ „ „ small „
Grand rameau „ „ large branch gallery,
Petit „ „ „ small „ „
Rameau de combat „ „ charging gallery.

The sizes of the above in the "École de Mines are given as:—

	Height.	Width.	Height.	Width.
	metres.	metres.	inches.	inches.
Galerie majeur	2·0	2·10	78	82
Grande galerie	2·00 or 1·85	1·0	78 or 72	39
Demi „	1·20 to 1·50	1·0	51 to 59	37
Grand rameau	1·0	0·80	39	31
Petit „	0·80	0·65	31	25
Rameau de combat	0·70 to 0·80	0·60 to 0·65	27 to 31	23 to 25

72. **Overcharged and undercharged mines.**—Experiments have shown that if h is the L.L.R., in order to produce an overcharged or undercharged mine having an index n (*see* Section 67) a charge of powder C_n found by the formula $C_n = gh^3(1+n^2-0{\cdot}41)^3$ must be used. This applies to all mines whose index n does not exceed 3, except those whose charge is less than that of the maximum camouflet mine (*see* Section 73).

The depth H at which the charge C_n will act as a common mine is

$$H = \sqrt[3]{C_n} = h\,(\sqrt{1+n^2}-0{\cdot}41).$$

TABLE of the values of $(\sqrt{1+n^2}-0{\cdot}41)$ and of $(\sqrt{1+n^2}-0{\cdot}41)^3$ as functions of n.

n.	$\sqrt{1+n^2}-0{\cdot}41$.	$(\sqrt{1+n^2}-0{\cdot}41)^3$.	n.	$\sqrt{1+n^2}-0{\cdot}41$.	$(\sqrt{1+n^2}-0{\cdot}41)^3$.
0·10	0·59	0·21	1·60	1·47	3·22
0·20	0·61	0·23	1·70	1·56	3·80
0·30	0·63	0·26	1·80	1·65	4·50
0·40	0·66	0·30	1·90	1·78	5·25
0·50	0·70	0·35	2·00	1·82	6·08
0·60	0·75	0·43	2·10	1·91	7·00
0·70	0·81	0·53	2·20	2·00	8·10
0·80	0·87	0·66	2·30	2·09	9·25
0·90	0·93	0·82	2·40	2·19	10·50
1·00	1·00	1·00	2·50	2·28	11·86
1·10	1·07	1·25	2·60	2·37	13·40
1·20	1·15	1·52	2·70	2·47	15·07
1·30	1·23	1·86	2·80	2·56	16·80
1·40	1·31	2·25	2·90	2·65	18·75
1·50	1·39	2·69	3·00	2·75	20·80

The depth p of the crater is given by

$$p = 0{\cdot}80\,(R-h) = 0{\cdot}80\,(\sqrt[3]{C_n}-0{\cdot}59h),$$

or by

$$p = h/3\,(2n-1).$$

These two empirical formulæ are specially suitable for values of n between 1 and 3. For $n = 1/2$, the second gives a zero value for the depth of the crater, which is approximately correct.

There are, moreover, the formulæ (*see* Section 69)

$$F = 1,\ 4R = 1,\ 4xh\sqrt{1+n^2}$$

and

$$f = \sqrt{2R^2-h^2} = h\sqrt{1+2n^2}.$$

73. **Maximum camouflet.**—The charge of the maximum camouflet that can be obtained at a depth h is equal to 1/5 of the charge that would produce a common crater for the same L.L.R. Moreover, a charge that will act as a common mine at a depth H, will act as a camouflet for all L.L.R. greater than 7/4, H which is the value of the L.L.R. of the maximum camouflet that can be obtained with the charge under consideration. These results can be deduced from the formulæ given in Section 72, if n is made zero. This is corroborated by practice.

74. **Curves of the edges of craters.**—Let O (fig. 8) be a charge of powder of a given weight C; the surface of the ground being tt', a crater having a radius $ab = r$ is obtained with L.L.R. $Oa = h$. If we call H the L.L.R. of the common mine having a charge C, we have (*see* Section 76)

$$H = h\,(\sqrt{1+n^2}-0{\cdot}41)$$

and substituting r/h for n (*see* Section 71)

$$r^2+h^2-(H+0{\cdot}41\,.\,h)^2 = 0,$$

r and h being the co-ordinates of the point b in terms of the rectangular axes Ox and Oy, it will be seen that if h varies and the point O remains fixed, all the points b will be found on an ellipse,* of which the longer axis is vertical and the shorter axis is horizontal, and of which the foci are the centre of the charge O and point O′, so that $OO' = H$.

The index of the mine, measured by the relation r/h corresponding to the tangent of angle KOb, increases continuously when point b moves along the arc of ellipse Kb_0, from K towards b_0, that is to say when the depth of the charge decreases progressively till it reaches zero. As regards the radius r of the crater, it is first zero, then it increases till the length AB is equal to the horizontal semi-axis of the ellipse, and then decreases; that is to say it passes through a maximum when $r = AB$; we then have $h = AO = H/2$, and by substituting $h/2$ for h in the formula $h\,(\sqrt{1+n^2}-0{\cdot}41) = H$, we find $n = 2{\cdot}2$ for the index of the overcharged mine which gives the greatest crater radius.

The formula $r = nh$ gives $AB = 2{\cdot}2 \times H/2 = 1{\cdot}1\,.\,H$. The radius of the maximum crater is thus not very much greater than the crater radius of the common mine with the same charge. As a result of this, in practice, the charge of an overcharged mine may be expressed as a function of the radius r of the crater with sufficiently exact approximation, by the very simple formula

$$C = gr^3;$$

it is, however, only advisable to use this when $n < 3$.

75. **Interior (underground) effects of any mine.**—For values of n less than 3, it is sufficient, in practice, in order to ascertain the radius of the compression chamber (*see* Section 70) and the radii of "limiting rupture" and "good rupture" of any mine (*see* Section 71), to take the common mine of the same charge.

76. **Effects of mines in disturbed ground.**—In ground where there has been a commotion due to previous explosions, the effect of explosives is greater than in undisturbed ground. Experiments have shown that, under these conditions, a given charge of powder produces the same exterior effects in light soil of double that charge in virgin ground, or in stiff soil of treble that charge.

77. **Intervals between two adjacent mines.**—When two mines are to act independently, interference with one by the explosion of the other is avoided if a minimum distance be left between them of from 3/4H to H for virgin ground, and of H to 5/4H where they are separated only by tamping; H being the L.L.R. of a

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* To demonstrate this, it is only necessary to write the equation of the curve referred to the same axis y and to a new axis x, parallel to, but above, at a distance $OA = H/2$. This equation is obtained by substituting x for r and $y+\frac{H}{2}$ for h in

$$r^2+h^2-(H+0{\cdot}41\,.\,h)^2 = 0,$$

then

$$x^2+\left(y+\frac{H}{2}\right)^2-\left(H+a\left(y+\frac{H}{2}\right)\right)^2 = 0,$$

where $a = 0{\cdot}41$. Noting that the coefficient of y, which is $H(1-a^2-2a)$ is zero, since $a = \sqrt{2}-1$, the foregoing equation may be written

$$\frac{x^2}{H^2\left(\frac{a+2}{2}\right)}+\frac{y^2}{H^2\left(\frac{a+2}{4a}\right)} = 1,$$

which is in the form of

$$\frac{x^2}{a^2}+\frac{y^2}{b^2} = 1,$$

that is to say that it is the equation of an ellipse in terms of its two rectangular axes. Point A is therefore the centre of the ellipse.

The distance from one focus to the centre is equal to

$$f = \sqrt{b^2-a^2} = H\sqrt{\frac{(a+2)(1-2a)}{4a}}.$$

Substituting for a its value $\sqrt{2}-1$, we find, after reduction, that $f = H/2$; as we have already taken $OA = H/2$, it is evident that point O, the origin of the primitive co-ordinates, is really a focus of the ellipse.

common mine having the same charge as the first mine. If this mine, however, is to be a camouflet, a distance equal to at least 7/4H must be left between the two mines (*see* Section 73).

78. **Horizontal line of least resistance.**—When the L.L.R. of a mine is horizontal, the radius and the volume of the crater are greater than in the case of a vertical L.L.R. It is often sufficient to fire a maximum camouflet, which by destroying the cohesion of the medium will, with the assistance of gravity, produce a considerable fall. The more resistance the medium offers, the smaller will be the advantage gained.

79. **Volume of a powder charge.**—The following table gives in cubic decimetres (dmc.) the volume V of a charge C, expressed in kilogrammes of powder having a density of 0·900, and also the measurement in metres (m.) of the inside a of a cube which will contain this charge (for density 0·832, *see* "École de Mines," Table C)

$$V = c/d\,;\; a = 10\sqrt[3]{C/d}.$$

If the charge is made up in cylindrical cartridges, the figures given in this table must be increased by 1/4 :—

Charge C.	d = 0·900.		Charge C.	d = 0·900.		Charge C.	d = 0·900.	
	Vol. V.	Side *a*.		Vol. V.	Side *a*.		Vol. V.	Side *a*.
kg.	dmc.	m.	kg.	dmc.	m.	kg.	dmc.	m.
1	1·11	0·11	30	33·3	0·33	400	444	0·77
2	2·22	0·14	40	44·4	0·36	450	500	0·80
3	3·33	0·15	50	55·6	0·39	500	556	0·83
4	4·44	0·17	60	66·7	0·41	550	611	0·85
5	5·56	0·18	70	77·8	0·43	600	667	0·88
6	6·67	0·19	80	88·9	0·45	650	722	0·90
7	7·78	0·20	90	100	0·47	700	778	0·92
8	8·89	0·21	100	111	0·49	750	833	0·95
9	10·0	0·22	120	133	0·52	800	889	0·97
10	11·1	0·23	140	156	0·54	850	944	0·99
12	13·3	0·24	150	167	0·56	900	1000	1·00
14	15·6	0·25	175	194	0·58	950	1060	1·02
16	17·8	0·27	200	222	0·61	1000	1110	1·04
18	20·0	0·28	250	278	0·66	1500	1670	1·19
20	22·2	0·29	300	333	0·70	2000	2220	1·31
25	27·8	0·31	350	389	0·73	3000	3330	1·50

Any air spaces that there may be around the charge before the explosion may be disregarded, so long as they do not exceed 10 times the volume of the charge.

MÉLINITE MINES WITH CONCENTRATED CHARGES ENTIRELY UNDERGROUND.

80. **General information.**—The use of mélinite for charging a mine is more expensive, and its decomposition gives rise to more poisonous gases than that of gunpowder; it is, however, less dangerous to handle, especially when in proximity to the enemy.

Experiments carried out up to date have not allowed of an exact determination of a law to connect the exterior and projection effects of a fixed charge of mélinite with the depth of the mine below the surface of the ground. In certain cases a charge of mélinite C_m is as powerful as a charge of powder C_p two and a-half times greater. We therefore have, as in the case of powder (*see* Section 70), a relation of the form

$$C_m = KV.$$

In the case of clay we may have $V = C_m/2$, C_m being expressed in kilogrammes and V in cubic metres. In the case of hard ground that is but slightly compressible, this fraction must be reduced by half.

Mélinite is therefore more suitable than powder for forming a mine chamber at the end of a boring. When it is used the compression chamber is not only larger but also more durable, because the surrounding soil has been very forcibly compressed. Almost double the weight of explosive originally employed can be placed in the chamber formed (*see* Sections 79 and 81).

There have not been a sufficient number of experiments with mélinite mines to enable precise rules to be given with regard to the action of this explosive on mine galleries and branch galleries (*see* Section 174).

81. **Volume of a mélinite charge.**—By calling V the volume of the charge in cubic decimetres, and C the weight in kilogrammes, we have approximately

Cast mélinite...	$V = \frac{C}{1 \cdot 8} = 0 \cdot 55\ C$
Mélinite in form of powder	$V = \frac{C}{1 \cdot 4} = 0 \cdot 7\ C$
"Pétards"* regularly packed together	$V = \frac{C}{1 \cdot 14} = 0 \cdot 9\ C$
"Cartouches"* regularly packed together	$V = C$
"Pétards" or "cartouches" hastily thrown together† ...	$V = 1 \cdot 5\ C.$

An air space left in the chamber of an underground mine has no harmful effect, even if it be equal to several times the volume of the charge.

MINES WITH CHARGES ARRANGED IN LENGTH.

82. **Powder charge parallel to the surface of the ground.**—A charge is described by its length l and the diameter d of the base of a cylinder of this length which can contain the charge, calculating only 630 kilogrammes per cubic metre, this will allow for any air spaces that may exist in a long charge (under these conditions a cylinder 20 centimetres in diameter contains 20 kilogrammes of powder per metre run).

When $l < 60d$, the bottom of the crater is oval in shape (fig. 9) and increases in length as the proportion of l to d (l/d) increases. When $l > 60d$, the bottom of the crater is a rectangle with oval ends.

The "lips" LL, which are thickest near the extremities of the shorter axis, and are lacking altogether at the ends of the longer axis, for a distance that will be the greater the more extended is the charge. The shape of the compression chamber (*see* Section 61) is approximately that produced by an oval of revolution on the axis of the charge, or of a cylinder with ovoid ends, according to the length of the charge.

83. **Formulæ for long mines.**—a and b being the two semi-axes of the crater (*see* Section 82), the proportion $m = a/b$ is given by the empirical formula

$$m = 0 \cdot 66\sqrt[4]{\frac{l}{d}+4},$$

which can be applied for values of l/d between 0·88 and 60 ($l/d = 0 \cdot 88$ in the case of a cube-shaped charge).

Experiments have also shown that the semi-axis b is equal to the base of the crater which would be obtained with a cube-shaped charge C/m placed at the same depth h as the long charge C.

We already have (*see* Section 72)

$$\frac{C}{m} = gh^3(\sqrt{1+n^2}-0 \cdot 41)^3.$$

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* Pétards are charges of mélinite in rectangular cases. Cartouches are charges of mélinite in cylindrical cases.

† "*En vrac*," an expression generally used of cargo put into a ship's hold without being properly stowed.

by substituting in this formula, b/h for n, and assuming

$$\sqrt[3]{\frac{C}{mg}} = H,$$

we obtain

$$b = \sqrt{(H+0{\cdot}41 = h)^2 - h^2},$$

and consequently

$$a = m\sqrt{(H+0{\cdot}41 = h)^2 - h^2}.$$

The depth $AE = p$ of the apparent crater (fig. 9) is given by the empirical relation

$$p = 0{\cdot}85\,(H - 0{\cdot}59h).$$

A very long powder charge, placed in a boring parallel to the surface of the ground and at a suitable depth, produces a long and narrow excavation of the genuine trench nature (bored saps, *see* Section 144).

84. **Long charges whose axis is vertical.**—No precise rules are known for the effects of mines with long charges whose axis is inclined. When this axis is vertical and $l < 60d$ (where it has the same meaning as in Section 82), and the mine acts as a camouflet, the compression chamber is an ovoid of revolution round the vertical axis, whose two extremities are almost identically the same. If a crater is formed, its edge is a circle, and it has a lip.

When the charge is very long the compression chamber has a central cylindrical portion, and if the ground be sufficiently compact there is a visible crater, a kind of cylindrical well widened out at its upper end.

85. **Mélinite mine with a long charge.**—Mélinite used in long charges in horizontal, inclined or vertical borings, produces compression chambers of greater capacity than is the case with the same charge of powder (*see* Section 80). Besides, due to the local effect of mélinite, the cylindrical shape of the chamber is much more marked than in the case of powder, and, in the majority of soils, the walls of the chamber are sufficiently hard for them to hold up, even when they overhang (bored shafts and branch galleries, *see* Sections 142 and 143).

MINES IN ROCK OR IN MASONRY.

86. **General information.**—For the destruction of masonry, although powder is more economical than mélinite, it is of advantage to use it only when at a distance from the enemy and there is time to tamp it thoroughly, either within or below the mass to be destroyed. Mélinite is suitable in all cases, and more especially when the walls to be destroyed are not very thick, or there is no time to make a long tamping.

87. **For powder.**—The formulæ for mines underground can be used, by giving a suitable value to the coefficient g (*see* Section 68).

Around the powder chamber the masonry or rock is completely shaken up for a distance r, which is practically the same in all directions and which is called the radius of rupture of the mine. This radius is only a little less than the crater radius when the crater index (*see* Section 67) is between 1 and 3. Therefore, calling the charge C, we have (*see* Section 74),

$$C = gr^3.$$

This formula is based on the supposition that the tamping does not give way when the mine is fired; otherwise, to maintain the same rupture radius the charge must be increased, that is to say that we must take $C = bgr^3$, b being a figure greater than unity, which is called the *tamping coefficient* (*see* Sections 121 to 122).

In a medium such as good masonry, the cohesion is very great in relation to the effects of gravity; there is no occasion, therefore, to take the direction of the L.L.R. into account when calculating the charges (*see* Section 78).

When it is a question of destroying a mass of masonry, the number of mines may be reduced by increasing r; this reduces the labour of boring, tamping, and firing. On the other hand, however, the amount of explosive used, $gr^3/2r$ or $gr^2/2$ per unit of length destroyed, increases rapidly with r.

88. **For mélinite.**—As regards the disruptive effects in rock or masonry, experience has shown that the charges of mélinite to be used with a light tamping (*see* Section 123) can quite safely be deduced from the corresponding powder charges (*see* Section 87) with complete tamping, if these are multiplied by the coefficient 3/4. The detonation of mélinite produces a chamber in ordinary masonry which may be estimated as being ten times the volume of the charge used.

89. **Mines under water.**—The exterior effect of an explosion of powder or mélinite is the raising of a column of water, which narrows towards the summit, instead of forming an inverted cone as in the case of earth. The interior effects are:—The production of a considerable pressure sufficient to burst submerged or floating hollow objects (boats), and of a violent shock capable of destroying bodies placed at right angles to the direction in which the pressure wave travels.

The action of a powder mine increases in intensity as the head of water above it is increased. The water really acts as tamping, the effect of which is naturally less marked when mélinite is used. When charges do not detonate in contact with the objects to be destroyed, the water acts as a shock absorber to these objects and damps down the shock due to the detonation; this preservative action is the more marked, the more powerful is the explosive. Speaking generally, therefore, endeavour should be made:—

1. To have as great a head of water over the charge as is possible, especially if powder is used;
2. To place the charges as close as possible to the objects to be destroyed under the water, especially if mélinite is used.

3. THE EFFECTS OF SURFACE CONTACT CHARGES AND CALCULATIONS FOR THEM.

90. **General.**—When powder is burnt in the open air, in contact with a body offering great resistance, such as iron, appreciable results are produced only when enormous charges are used. It is not worth using, therefore, in these circumstances. It may be used on occasion in contact with bodies such as masonry buildings or wood of medium thickness, and heavy charges must be employed. These experimental facts may be summed up by the statement that powder is not effective if untamped. The action of surface contact charges of powder is considerably increased if they are covered up by even light objects: turf, planks, tarpaulins, &c., or if they are enclosed in strong receptacles.

Surface contact charges are quite satisfactory if mélinite (or dynamite or guncotton) are used, for the disruptive effects of these agents ensure complete rupture in even the strongest bodies which are directly and immediately opposed to the charge, with easily handled quantities of explosive. In this case, as a result of their inertia, the molecules of atmospheric air form sufficient tamping to prevent a premature drop of pressure of the gaseous mass which is produced by the almost instantaneous decomposition of the explosive. Nevertheless, rough tamping by means of any solid or liquid body considerably increases the useful effect, for it will allow the gases to attain a higher maximum pressure.

91. **Number of pétard elements.***—When mélinite is used for charges in contact with a surface it is often necessary—owing to the local effect—to make the charge as long as the demolition desired. Long charges are therefore used, the amount of which is either expressed as so many kilogrammes per metre run, or by the number n of 135 gramme pétards, placed lengthwise, that which must be laid side by side; n is then what is called the *number of pétard elements.* The following relationship exists between n and the charge c per metre run:—

n	1	2	3	4	5	6	7	8	9	10	
c	0·91	1·82	2·73	3·64	4·55	5·45	6·36	7·27	8·18	9·1	kgs.

Practically the charge in kilogrammes per metre run is equal to 0·9 n.

92. **Destruction of metal structures.**—High explosives are used to the exclusion of powder. In the open air the action on a metal plate of a mélinite charge

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* Charges in rectangular cases.

capable of producing complete rupture is localised in the immediate neighbourhood of the charge. As the explosion is instantaneous, and as a result of the inertia of the matter acted upon, the rupture takes place almost without there being any movement of the object as a whole. (This, however, does not prevent splinters being scattered, sometimes to a considerable distance.) The result of this is that the rupture occurs in practically the same manner and with the same quantity of explosive, whatever the distance between the supporting points of the object may be and whatever the position of the rupture line may be in relation to those points. This is not the case, however, when the charge is too weak to occasion complete rupture of the object, the latter then suffers distortion.

93. **Form of, and manner of, placing the charge.**—The maximum result is obtained when the charge is very compact with regard to its axis, when it is uniformly applied along the whole width of the rupture section desired, and when the contact between the charge and the metal is as close as possible. The effect of these conditions is to make the charge a prism, with a cross-section approaching as closely as possible to a square. Fig. 10 shows that the use of "cartouches"* for the charge must be avoided, as they will not be sufficiently in contact with the metal, and will have air spaces between them.

To break a metal plate, therefore, there should be placed along its whole width and following the rupture line required a long charge consisting of groups of pétards in contact with each other, and placed lengthwise. The detonator container should be turned towards the primed pétard (*see* Section 177).†

If it is found advisable to distribute the charge on both sides of the plate, the two portions of the charge should be placed in chequerwise ("École de Mines," 284) and so that their action may be combined to produce a shearing action. If two lines of pétards are placed opposite each other, the rending forces of their explosion would neutralize each other, and only the crushing action can be counted on, which would not be sufficient to bring about a rupture in the case of substances as hard as iron and steel.

94. **Calculating the charge.**—The number of pétard elements n (*see* Section 91) of a long charge required to break a metal plate increases with the total thickness e of the latter (at right angles to the breakage line), and, for the same thickness, with the number m of riveted sheets of which the plate consists. If the total thickness e is expressed in centimetres (not including the heads of the rivets), the empirical equation is $n = 2/3me$.

As this formula is sufficient for steel, it gives slightly exaggerated charges for iron and plates built up of sheets less than 6 millimetres in thickness.

If the groups of pétards are placed end to end, perpendicularly to the greatest dimension of the part to be destroyed, and the end of the first bundle of pétards is brought level with one of the edges of this part, if l, expressed in centimetres, like e, is the transversal length of the remaining part left over, less than the length of a pétard (14·85 or practically 15 centimetres), the number of pétards n' theoretically necessary to break this remaining length is given by the formula

$$n' = \frac{l}{15} \times 2/3, me = \frac{mel}{20} \text{ approximately.}$$

This latter formula can always be used for calculating the number of pétards required to destroy a structure, or a portion of a structure, whose width was less than the length of a pétard if it were possible to cut across a group of pétard elements (ascertained by $n = 2/3, me$), in order to take a portion of it equal to l in length. As, however, pétards are used whole, it is necessary in the majority of instances to increase the theoretical charge in order to obtain a thickness of mélinite at least equal to that of the group of elements.

In the case of a single sheet, the formula $n = 2/3me$ is reduced to $n = 2/3e$.

95. **Demolition of beams, &c., of wood.**—For this purpose mélinite is preferable to powder. Powder can, however, be usefully employed under water for the demolition of wood (*see* Section 164).

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* Cylindrical cartridges.

† The trench pétards have a detonator container somewhat similar to that in the Hales rifle grenade.

DIAGRAMS TO ACCOMPANY TRANSLATION OF CHAPTER II OF ÉCOLE DE MINES. LIVRE DE L'OFFICIER.

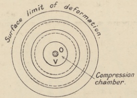

Fig. 1. Effects of explosion in an unlimited medium.

SECTION THROUGH CENTRE OF CHARGE.

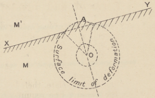

Fig. 2. Case of several media. line of least resistance.

VERTICAL SECTION.

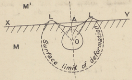

Fig. 3. Formation of a crator.

VERTICAL SECTION.

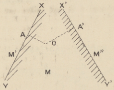

Fig. 4. Case of several lines of least resistance.

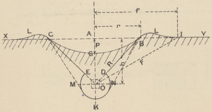

Fig. 5. A Mine in Earth.

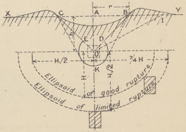

Fig. 6.

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Malby & Sons, Lith.

DIAGRAMS TO ACCOMPANY TRANSLATION OF CHAPTER II OF ÉCOLE DE MINES. LIVRE DE L'OFFICIER.

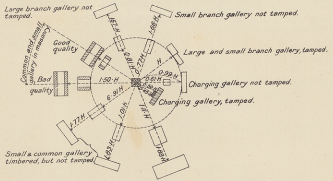

Fig. 7. Limit of action of mines on various galleries.

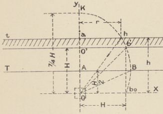

Fig. 8. Curves of the edges of craters.

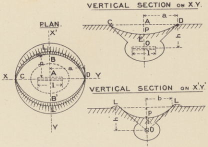

Fig. 9. Mine with a long charge.

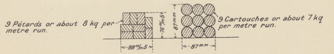

Fig. 10. Comparison of charges formed of pétards and of cartouches.

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Malby & Sons, Lith.

Mélinite damages wood to a greater extent than metal, and its crushing action adds considerably to its rending effects. In consequence, contrary to what has been found in the case of metals, there is nothing to prevent portions of the charge being placed directly opposite each other. To fell a tree or to cut through a felled tree, the pétards may be placed in a ring right round it, perpendicularly to the axis of the tree. In the case of a squared piece of timber, the charge should be placed on the widest side, it being unnecessary to adhere to such a precise distribution of the charge as is the case when a piece of metal is to be cut.

The total charge is ascertained by multiplying the section by a coefficient which depends upon the hardness of the wood (*see* Section 195, *et seq.*).

96. **Destruction of masonry.**—Mélinite is much preferable to powder for the destruction of masonry by means of surface contact charges. With equal charges of mélinite, if the wall is not thick, the work is done more quickly and more certainly if a bore is made and the explosive is placed in it. Concentrated surface contact charges are generally calculated by means of a formula

$$C = Ke^3.$$

In the case of long surface contact charges, the charge c per unit of length is given by formula

$$c = K'e^2.$$

In these formulæ, e is the thickness of the wall to be pierced, K and K′ are coefficients that depend chiefly upon the width of the breach and the nature of the material of which the wall is built.

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$$C = Re^3$$

In the case of long surface contact charges, the charge c per unit of length is given by formula

$$c = R'e^2$$

In these formulae, e is the thickness of the wall to be pierced, R and R' are coefficients that depend chiefly upon the width of the breach and the nature of the material of which the wall is built.

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[FOR OFFICIAL USE ONLY.]

ARMY COUNCIL INSTRUCTION.

No. 535 of 1917.

WAR OFFICE,
28th March, 1917.

535. Instructions for the guidance of officers responsible for the storage of small quantities of explosives in temporary stores.

1. Whenever possible explosives will be kept in a regular magazine or explosives store.

2. If a temporary store must be used, it should be so situated that, in the event of an accident, as little damage as possible either from the explosion itself or subsequent fire may occur. Quantities will be kept down to the absolute minimum.

3. On no account will explosives be stored in a living room.

4. Buildings which contain explosives will be kept under the following conditions :—

- (i) They will be treated as explosives stores and come under the Regulations for Magazines and care of War Matériel as far as possible (A.C.I. **1893** of 1916).
- (ii) Demonstrations or experiments with explosives, puffs, live grenades or live bombs, fuzes or detonators, are in no case to take place inside any building, they will be carried out with the greatest care, and only by individuals who have received expert training and are thoroughly reliable (A.C.I. **2081** of 1916).
- (iii) No exposed lights, fires, smoking or matches are to be allowed in them.
- (iv) They must be kept clean. No inflammable goods or liquids, oils, rags, cotton waste or anything liable to spontaneous ignition may be left in them.
- (v) Doors and windows must be kept locked. If opened for ventilation someone will be placed in charge.
  The key must be in charge of some authorized person. A notice will be posted up stating how it is to be obtained.
- (vi) Filled buckets of water will be kept near all buildings where any explosive is stored or handled, perferably just outside the door.
- (vii) Issue in bulk of an explosive is not to take place in the room where explosives are stored, or in proximity to other explosives.

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5. If a store gets on fire and it is clearly impossible to put the fire out, there is no object in remaining within the radius of danger from its explosion. Explosives which, unconfined in small quantities will burn off, may burn to detonation in larger quantities or when confined in bombs, etc.

6. The explosives most likely to be used for trench warfare purposes are printed overleaf.

It is advisable to keep all explosives separate from each other in storage as far as possible. Those bracketed together in the last column may be grouped together for storage if necessary. Every explosive in bulk will be in a covered receptacle, preferably sealed.

40/W.O./3691 (A. 3).

By Command of the Army Council,

R H Brade

[Copies for G.Os.C.-in-C. and G.Os.C. at Home and Expeditionary Forces; D.D.O.S., Woolwich Arsenal.]

Explosives most likely to be met with for Trench Warfare purposes.

Explosive.	Composition.	Characteristics.	Rules for Storage.
Gunpowder and gunpowder puffs	Potassium nitrate, sulphur, charcoal	Very easily ignited by a spark or flame.	Keep covered in small quantities, apart from other explosives. Anything more than 1 lb. should be in a sealed receptacle. The bulk should never be used for doling out small quantities.
Safety fuze	Gunpowder enclosed in waterproofed jute sheathing	Exposed end easily ignited by spark or flame.	Keep in tin or box with lid.
Instantaneous fuze ...	Quickmatch enclosed in waterproofing tape	Exposed end easily ignited by spark or flame.	Ditto.
Ophorite	Potassium perchlorate, magnesium powder	A silvery powder used as a bursting agent in some trench howitzer ammunition. Detonates violently from flame. Is sensitive to friction or blow, which is very greatly increased in the presence of an easily oxidizable substance such as phosphorus.	This is a dangerous explosive if not handled properly. Keep only in very small quantities in covered receptacle and apart from all other explosives. Never use the bulk for doling out small quantities.
Guncotton, dry	Nitrated cotton	Sensitive to flame and friction, liable to flake. If unconfined in small quantities will burn away. Liable to spontaneous ignition when old.	Keep in covered receptacle, away from all other explosives and in cool position.
Tonite	Nitrated cotton, barium nitrate ...	Ditto	Ditto.
Guncotton, wet	Nitrated cotton with about 16 per cent. of water	Insensitive to flame till dried. Requires a detonator.	Keep in watertight receptacle, so that moisture is not evaporated. If becoming dry dip in solution of water and a little carbolic solution till wet weight is made up (1 oz. carbolic to 1 gallon of water).

Explosive.	Composition.	Characteristics.	Rules for Storage.
Ammonal	Ammonium nitrate, T.N.T. (tri-nitro-toluene), aluminium powder (with or without 3 per cent. charcoal)	Moderately difficult to ignite by flame. Will burn away in small quantities unless confined. Insensitive to blow or friction. Hygroscopic. Requires a detonator. Used for filling bombs, grenades, &c., for trench warfare.	Keep in air-tight receptacle in dry storage.
Alumatol	As above, with only 3 per cent. of aluminium and no charcoal	Ditto	Ditto.
Amatol and abelite	Ammonium nitrate, T.N.T.	Ditto	Ditto.
Sabulite	Ammonium nitrate, T.N.T., calcium silicide	Ditto	Ditto.
Detonating fuze (Cordeau Bickford) or Cordeau Detonant	T.N.T. in lead tube	Requires a detonator at one end when whole length will detonate. Not hygroscopic.	Keep in a box.
Blastine	Ammonium perchlorate, sodium nitrate, di-nitro-toluene, paraffin wax	Will burn more fiercely than ammonal and other ammonium nitrate explosives and is not quite so insensitive to blow or friction. Hygroscopic, but less so than ammonium nitrate group. Used for trench warfare ammunition.	Keep air-tight receptacle in dry storage.
Detonators	Fulminate of mercury or other sensitive mixtures	Easily detonated by flame friction percussion or rough usage such as dropping or being trodden on. Never force a detonator. They are easily spoilt by moisture.	Keep apart from all other explosives, as these are used for detonating high explosives. Never carry them loose in your pocket but in a box, the detonators being packed in soft material. Sawdust may be used provided it is dry; if not the detonators will quickly deteriorate. Do not leave detonators in bombs or grenades in store.
Thunder flashes	Potassium chlorate, barium nitrate, fine aluminium	Detonated by flame; powerful composition.	Keep in small quantities and apart from other explosives.
Flares	Various illuminating compositions	Sensitive to flame	Keep in covered receptacle in dry storage.
Fireworks	Various mixtures	Ditto	Ditto.
Mills' grenades or other filled bombs or grenades	Filled ammonal or kindred explosives	Require a detonator, but may detonate if heated up by a fire.	Store without detonators in dry place.
Smokeless powder (propellants)—			
Cordite, ballistite	Gelatinized nitro-cellulose with nitro-glycerine	Sensitive to flame; liable to decomposition on long storage.	Keep in covered receptacle, in cool storage. Keep nitro-cellulose well sealed or ballistics will be affected.
Nitro-cellulose	Gelatinized nitro-cellulose without nitro-glycerine.	Ditto. Moisture content readily varies with atmospheric conditions.	Ditto.